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CONTENTS

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THE IMPORTANCE OF MOLD ACTION IN SOILS[1]

THE development of soil bacteriology during the last decade has been truly remarkable. Many fundamental problems connected with the occurrence and activities of bacteria in soils have been attacked and considerable progress has been made toward their solution. While much work still remains to be done along this line, results already secured show, in a rather definite way, the importance of bacterial action in soils from the fertility standpoint.

According to recent investigations, however, bacteria are not the only microorganisms which exert an influence on soil fertility. Molds, protozoa and algæ have been found quite commonly, and evidently their action, especially that of molds, must also be considered in determining the crop-producing power of soils. The subject of microorganic life in the soil has, therefore, been considerably broadened and complicated.

The occurrence of molds in soils has been noted many times in the past in connection with bacteriological and other studies and various investigations have dealt in a more or less general way with the action of these organisms. It is only within the last year, however, that an attempt has been made in a logical and comprehensive manner to study the occurrence, distribution and activities of molds in soils, and to solve some of the fundamental problems which arise in connection with the growth of these organisms. The results secured at the New Jer-

[1] Paper presented at the meeting of the Society of American Bacteriologists, at New Haven, Conn., December 27, 1916.

sey Agricultural Experiment Station,[2,4,5] not only furnish a basis upon which future experiments may rest, but they also indicate quite distinctly that the growth of molds in the soil may be of great significance.

The transformation of organic and inorganic compounds in the soil has long been considered the particular function of soil bacteria, but molds may also play an important rôle in such processes, and indeed it is conceivable that in some instances they may prove largely responsible for the simplification of complex soil materials.

It is not the purpose of this paper to review the previous studies on molds, for excellent bibliographies have been presented in the work of Waksman[4] and Coleman[2] already referred to. It is desired merely to call attention in a brief way to the varied action of molds in soils, and to present a compilation of various published data and some of our own unpublished results along this line, with the idea of emphasizing the need of further study of these organisms.

In the first place, the number of molds in soils should be considered, and while data along this line are far from conclusive, it has been shown that large numbers of these organisms are always present. Especially is this true for soils rich in humus, and acid in reaction. But the occurrence of fungi is not restricted to such abnormal soils. Neutral, well-aerated and well-fertilized soils are also found to contain rich mold floras. Furthermore, fungi are not limited merely to the surface soil, but occur in the deeper soil layers. The well-known predilection of certain fungi for acid conditions has been confirmed and leads to interesting conclusions regarding the special importance of these forms in acid soils in which beneficial bacterial action is largely restricted.

A very important point in connection with the occurrence of molds in soils has been studied recently by Waksman.[5] While the counting methods employed have shown the large numbers of molds in soils, considerable doubt existed as to whether these counts represented the actual number of active fungi or only the spores. If spores alone are present, the activity of molds in soils may be of less immediate importance although their presence would indicate previous active growth as well as future activity when the soil conditions become satisfactory for the development of active forms from the spores. Active mold growth on the other hand would undoubtedly be of immediate importance in the chemical changes occurring in the soil. The value of definite information along this line is apparent. The careful experiments of Waksman show that many molds occur in soils in an active state as well as in the form of spores. While certain groups do not appear to be present in an active condition in the soils tested, although the plate method showed their occurrence as spores, studies of other soils may lead to different conclusions.

Conn[3] has attempted to check Waksman's results by the use of smaller quantities of soil, but was unsuccessful. Using 10 mg. of soil, he secured no growth of mold mycelia such as Waksman obtained with lumps of soil 1 cm. in diameter. He describes a direct microscopic examination of soils and finds no mold mycelia present. He concludes from these experiments that there is serious doubt whether molds exist in soils in an active form *in sufficient num-*

[2] Coleman, D. A., "Environmental Factors Influencing the Activity of Soil Fungi," *Soil Science*, Vol. II., No. 1, p. 1.

[3] Conn, H. J., "Relative Importance of Fungi and Bacteria in Soil," Science, N. S., 44, p. 857.

[4] Waksman, S. A., "Soil Fungi and Their Activities," *Soil Science*, Vol. II., No. 2, p. 103.

[5] Waksman, S. A., "Do Fungi Actually Live in the Soil and Produce Mycelium?" Science, N. S., 44, p. 320.

bers to be important compared with bacteria. There seem to be two questions involved here: How large a proportion of the number of molds developing on plates represent active forms and how many spores? What is the number of active mold forms which need be present in the soil for them to be considered important in the various soil chemical processes?

The first of these questions is rather difficult to answer at the present time, but our experiments indicate that rather a large proportion of the total number of molds present in various soils occur in the active state. We have found active mold growth occurring in all the soils thus far examined, and we have used both Waksman's and Conn's methods. Our results confirm Waksman's observations, therefore, and Conn's criticism seems unwarranted, for *active mold mycelia have developed in all our tests, using not only 10 mgs. but also smaller quantities of soils, as well as* the larger lumps employed by Waksman. The soils tested are normal soils, many of them untreated and none extremely rich in humus.

Further work along this line is certainly desirable, but from our observations thus far there seems no doubt but that *fungi occur actively in soils,* and hence we feel that their action must be important regardless of their relative numbers compared with bacteria. Furthermore the presence of spores is likewise important for they may become active in the near future and bring about their characteristic reactions. The answer to the second question mentioned above can only come after long-continued experiments, but from the vigorous action of molds noted in so many cases, as will be pointed out later, it is evident that the problem of microorganic activity in relation to soil fertility can not be completely solved without a knowledge of mold growth. Perhaps they are not as important as bacteria, there is no means yet of knowing, but even if of secondary significance they deserve recognition. Our present knowledge of soil fertility is too incomplete to permit us to pass over hastily any possibly important factors without thorough study.

We believe, therefore, that molds occur in most soils, both in the active and in the spore state, and hence they must pass through their various life cycles in the soil. Furthermore, different soils undoubtedly have different fungus floras. Species present under one combination of conditions may be absent under others. Organisms present only as spores in one case may occur actively in other instances. Finally, it seems perfectly possible that the relative occurrence of active and spore forms of various organisms may vary in the *same* soil with varying conditions of moisture, temperature, aeration, reaction and food supply.

Considering the occurrence of molds in an active state in all soils an established fact, the importance of these organisms in the decomposition of the soil organic matter becomes evident. Many experiments have been conducted along this line and it has been very clearly demonstrated that molds are very efficient ammonifiers. Indications have been secured that there exists a correlation between the biological stage of the organisms and the periods of ammonia accumulation. The largest amount seems to accompany the periods of spore germination and the smallest amount the time preparatory to actual spore formation.

All the nitrogenous organic materials which make up the humus content of soils are easily attacked by various fungus forms and ammonia is liberated in large amounts. Part of this ammonia may, of course, be utilized by them, but by far the larger part

is set free and may be subsequently nitrified for use by the higher plants. Various fertilizing materials containing complex nitrogenous compounds may be ammonified by soil fungi, and their decomposition considerably facilitated. For instance, experiments with cyanamide show its rapid transformation to ammonia by certain molds. Ammonia production from urea by molds has also been definitely proven.

The non-nitrogenous portion of the soil organic matter is also attacked by many molds. Thus experiments have shown that cellulose is rapidly decomposed by many species, and other substances such as sugars, pectins, oils, fats, waxes, organic acids, etc., are likewise broken down by molds. Some recent results secured in our laboratories show the large carbon-dioxide production by molds. No doubt, therefore, remains but that these organisms play an extremely important part in the decomposition of all soil organic matter and indeed certain results indicate that their action along this line may be much greater than that of bacteria, at least under certain soil conditions.

No experiments have yet been reported which indicate that molds may bring about nitrification, and this process, therefore, still appears to be purely bacteriological. Further experiments may modify this conclusion.

Denitrification and deazotofication, however, processes now known to be of slight significance in normal soils, but which may occur in highly manured, specially treated greenhouse and market garden soils, may possibly be brought about by the action of molds. The introduction of these organisms with the manure used may be an important factor here. Definite data along this line are lacking at the present time.

Non-symbiotic nitrogen fixation, or azofication by molds has been studied from time to time and indications have been secured that certain species may be able to utilize the nitrogen of the atmosphere. The results, as a whole, however, are far from satisfactory and indeed the conclusion has been drawn that at the present time the "weight of the conclusions on the fixation of nitrogen by fungi seems to be on the negative side." Further experiments along this line are certainly desirable.

The utilization of various nitrogen compounds by molds has been studied to some extent, and it has been found that ammonia and nitrate compounds are assimilated by these organisms in considerable amounts. Thus under extreme conditions of mold growth it is conceivable that molds may be actual competitors with the higher plants for nitrogenous food materials. It is not believed, however, that such conditions would occur except very rarely. A knowledge of mold growth in soils may be of some significance, nevertheless, in connection with the questions involved in the fertilization of soils with nitrates and ammonium salts.

The decomposition of mineral compounds in soils by molds has been studied only to a very slight extent. Data secured in our laboratories very largely in connection with certain chemical and bacteriological studies indicate, however, that these organisms may play an extremely important rôle, not only in preparing nitrogenous food materials for plants as has been indicated, but also in making other mineral constituents available. Complete data along the various lines indicated will be published later.

Studies of the production of available phosphorus by bacteria and molds have shown the vigorous action of various fungi in this direction. Several experiments carried out by various methods have shown that rock phosphate is apparently transformed much more rapidly into a soluble form by many molds than by bacteria. The importance of further study along this line

in connection with the solution of the moot question regarding the relative merits of rock phosphate and acid phosphate can readily be seen.

The oxidation of sulfur in the soil, or sulfofication, a process which has recently received some attention and which gives evidence of being of great importance from the soil fertility standpoint has been shown to be accomplished by several species of molds. The action of these organisms in this process may become of special importance in connection with the recent suggestion for the production of available phosphorus by composting rock phosphate, sulfur and soil or manure.

The process of ferrification, or iron oxidation in soils, while largely chemical in nature according to results thus far secured, is brought about partly by microorganisms and certain molds are apparently much more active in this action than any of the bacteria studied.

Experiments on the production of available potassium by molds should also yield interesting results. No data have yet been secured on this point.

In fact, it seems evident that mold action in soils may be of far greater significance than has previously been supposed in preparing available food for plant growth. No longer should the study of microorganic activities in soils consider bacteria alone. Mold action must also be investigated, and in most cases it is undoubtedly true that only vague, incomplete results can be secured if such mold studies are not included. Many results secured in bacteriological investigations might be explained and interpreted much more clearly and definitely if the activities of molds were considered.

If soil bacteriology is to be developed to the proper extent in the future and the relation of microorganisms to soil fertility is to be established with any degree of certainty, investigations must include not only bacterial action, but the activities of molds and possibly also the growth of protozoa and algæ.

It is certainly desirable that the investigations of molds in soils and their activities and importance be carried out much more generally and on a larger scale than is the case at present. Here is a field of study rich in possibilities and the importance of work along these lines can not be questioned.

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THE U. S. BIOLOGICAL STATION AT BEAUFORT, N. C., DURING 1916

THE general appearance of the site of the station was materially enhanced during the year by enlarging the improved portion of the grounds, and by planting grass, sea oats, trees, and shrubbery. Through these improvements the comfortableness of the station was also increased. The laboratory, as usual, was open during the summer to special investigators. The investigators, with a single exception, had engaged in research at this station before and they continued during the past season lines of work previously undertaken.

The present large series of experiments in diamond-black terrapin culture, which was started in 1909, has progressed with marked success. Several new experiments in addition to those already under way were undertaken. There are now approximately 1,600 terrapins, exclusive of the young of 1916, in the pounds which are being used for experimental purposes. This experimental work has shown quite conclusively that terrapins can be grown and kept in vigorous condition in captivity, for some of the earliest broods, hatched in the pounds at the station, have reached maturity and are very prolific in the production of eggs, and the offspring is equally as vigorous as that of the wild terrapins confined after maturity had been attained.

A total of 2,611 terrapins hatched during the summer of 1916 has to date been taken from the egg beds. This number will be some-